Propulsion Controlled Aircraft: A Safety and Survivability Enhancement Concept

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ADPA/NSIA Symposium
Enhancing Aircraft Survivability

Propulsion Controlled Aircraft: A Safety and Survivability Enhancement Concept

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Paper for the American Defense Preparedness Symposium on Enhancing Aircraft Survivability, Oct 21-23, 1997, Naval Post Graduate School

Modern aircraft with today's advanced technology have achieved an astounding safety record. However, as the number of operations continues to increase, we need to continue to examine methods to survive extremely unlikely failure scenarios. Triggered by the Sioux City accident, we at NASA Dryden have been looking at flying airplanes that have lost all flight controls. Such a loss could occur not only from battle damage, but from uncontained engine failure, mid-air collision, terrorist bomb or missile, structural failure and control system failure.

Flight control using only manual throttle control has been extensively studied. Our results substantiate the experience of The flight 232 crew; that manual throttle control landings range from very difficult to impossible, depending on the aircraft configuration. NASA Dryden developed what came to be called the Propulsion Controlled Aircraft or PCA system, using computerized control of engine thrust, and, with PCA, safe landings are possible for many airplanes. Flight tests of an F-15 and an MD-11 have demonstrated landings without the use of any of the normal flight controls. In addition, a PCA system was developed at NASA Ames and has been proven on a high fidelity simulation of the B-747. and by Boeing on a C-17 simulation have also shown safe landing capability.

These PCA systems used full authority control of the engines, and thus would require digital engine controls and modifications to the engine control software. In the new NASA spirit, we looked at Faster - Cheaper and maybe good enough variations on the PCA theme. Pitch control may be adequately provided by driving the engines through the autothrottle system that exisits on many of today's airplanes. On the B-747-400, using the autothrottle system and the existing 5% digital engine trim capability, safe landings could still be made. We call this PCA-Lite. It worked well in turbulence levels to light-to-moderate and crosswinds to 10 knots.

For airplanes with autothrottles but without digital engine controls, we looked at whether the pilot could manually manipulate the throttles to provide the differential thrust for lateral control. On the B-747 simulator, the answer was clearly yes; this became "PCA Ultra-lite". On the MD-11 simulator, with the engines more inboard, results were not as good...the landing were probably all survivable, but it was very difficult to land on the runway because of the sluggish lateral control capability with manual thrust control. This concept is just starting to evolve, and more airplanes need to be examined.

For the really-really-really bad day where you lose flight controls and also lose a wing engine, if only the engine or engines on one wing were still operating, would there be any possibility of providing emergency flight control? In response to this potential situation, NASA Dryden has taken a first look at a concept that shows that one engine can provide limited flight control capability if the lateral center of gravity (CGY) can be shifted toward the side of the airplane that has the operating engine. Limited simulation tests with all conventional flight controls inoperative and a wing engine inoperative on the MD-11 have shown positive flight control capability within the available range of lateral CG offset. On 4-engine airplanes, simulations of the B-720 at NASA Dryden, and the B-747 at NASA Ames, have also shown positive control capability within the available range of CGY offset.

Overall, the response of engines as flight controllers has been adequate. Transport engines are slower to respond, but those airplanes also have slower dynamics; the net result has been that engine response has been fast enough to damp aircraft dynamics. There have been cases where the thrust level was near idle and engine response became very slow, particularly for landings with no flaps. Shallower glideslope approaches helped this problem.

In summary, engine thrust can be used for airplane flight control. Manual thrust control is OK for continuing flight, but is not adequate for landing. A system that uses computer-controlled thrust has been shown to provide safe landing capability for fighter and transport airplanes. Simplified versions of this PCA system have also been studied recently, and also show promise for emergency landings.

WHY Throttles-Only Control Research?

NASA
FWB 92-53f

Numerous aircraft accidents caused by loss of primary flight control system

- **JAL B-747 in Japan** hyd, struc fail
- **UAL DC-10, Sioux City** hyd, engine fail
- **C-5 Vietnam** hyd, struc fail
- **F-18, Indiana** hyd leak
- **F-18, Japan** FCS LVDT failure
- **Turkish DC-10 at Paris** Cables, baggage door
- **B-52H, Patterson, AFB** hyd leak
- **F-14 #1, Long Island** hyd leak
- **XB-70, Edwards** lost vertical/rudders, mid-air
- **18% of SEA (Vietnam) losses** Various

Other incidents were not accidents because of exceptional crew skill

- **A-10 Desert Storm** AAA/Cables
- **Delta L-1011 at LAX** Jammed stab
- **B-52G, Robbins AFB** hyd leak

NTSB Recommendation from the UA232 accident:

"Encourage research and development of backup flight control systems for newly certified wide-body airplanes that utilize an *alternate source of motive power* separate from that source used for the conventional control system"

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Airplanes Studied

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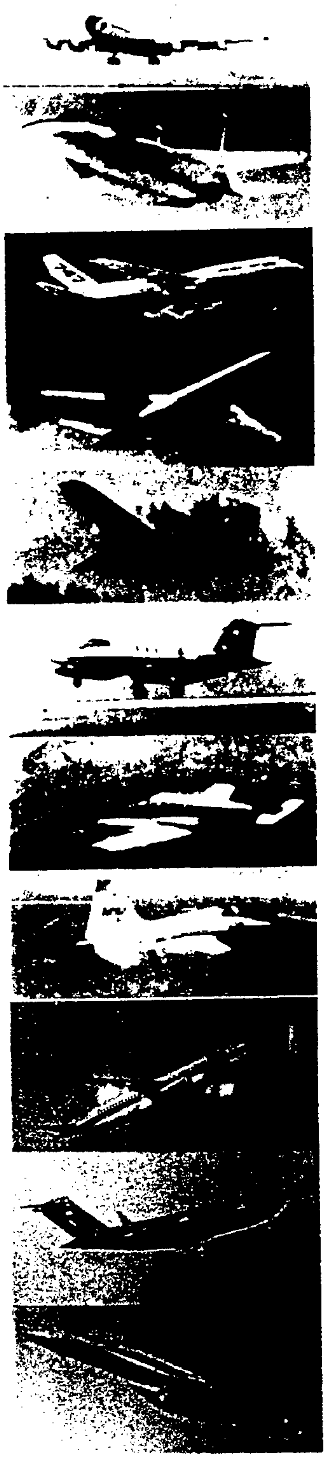
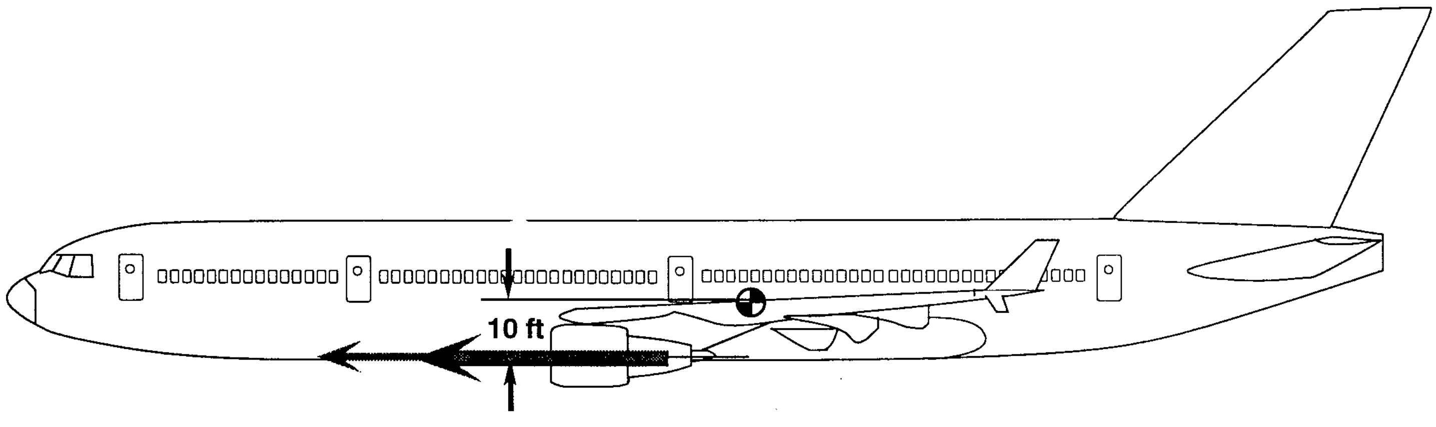
FWB 92-54c



	Simulation	Flight
B-720	●	
F-15	●	●
B-747	●	●
MD-11	●	●
B-727	●	
MD-90	●	
Learjet		●
& T-39		●
PA-30		●
C-402	●	
T-38		●
ACFS Generic Twinjet	●	
C-17	●	●
F-18	●	●

To climb, add thrust on the wing engines



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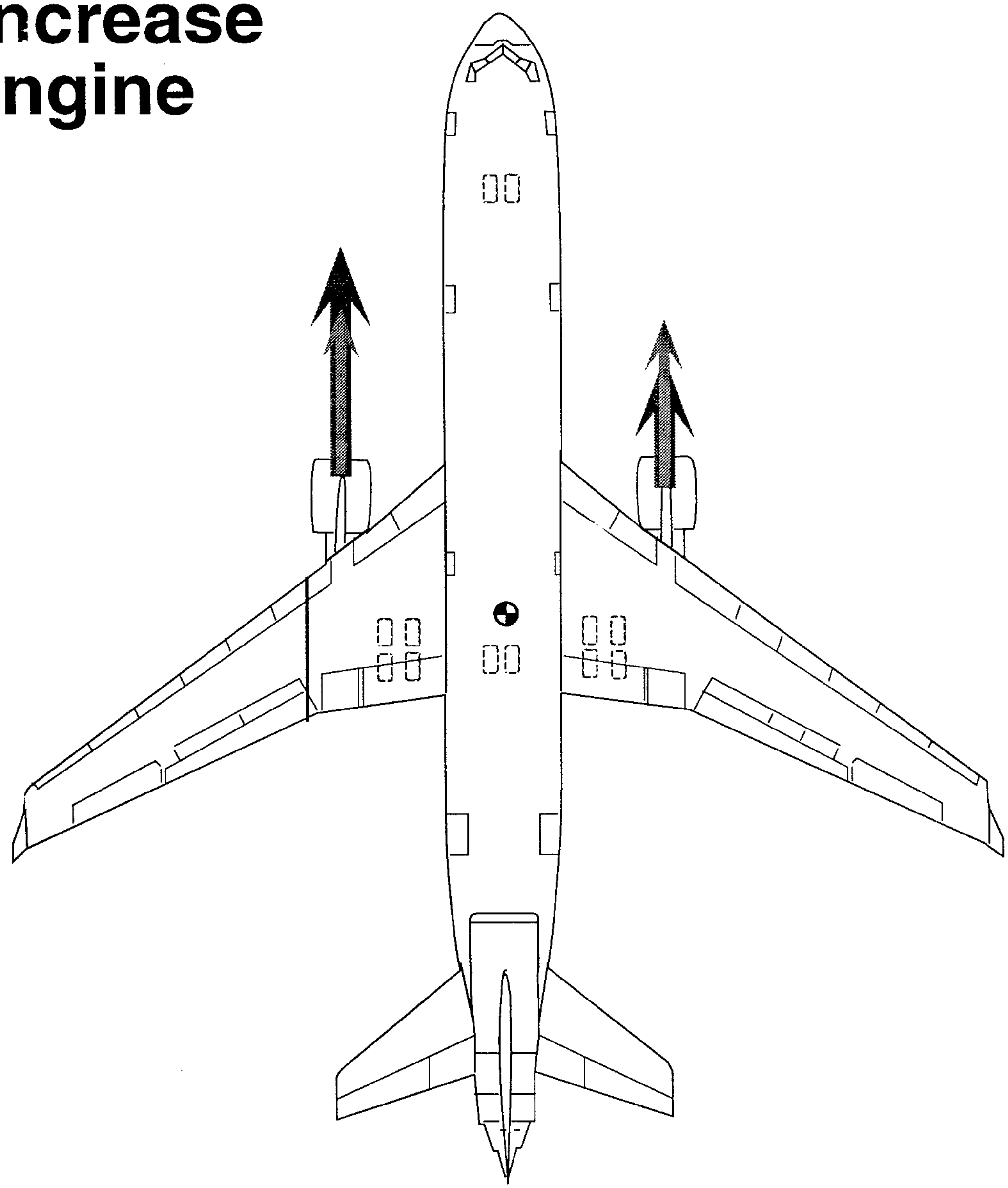
To turn right, increase thrust on left engine



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Manual Throttles-Only Control

- Varies greatly from aircraft to aircraft
  - primary factor: engine location
- Very high pilot workload, significant training factor

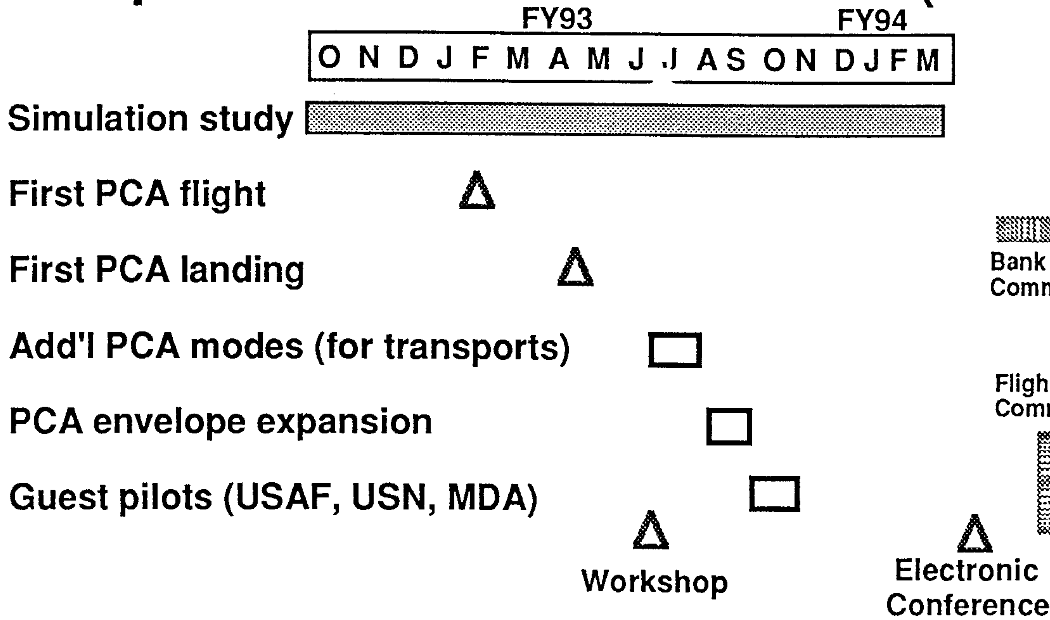
Usually adequate for up and away flight

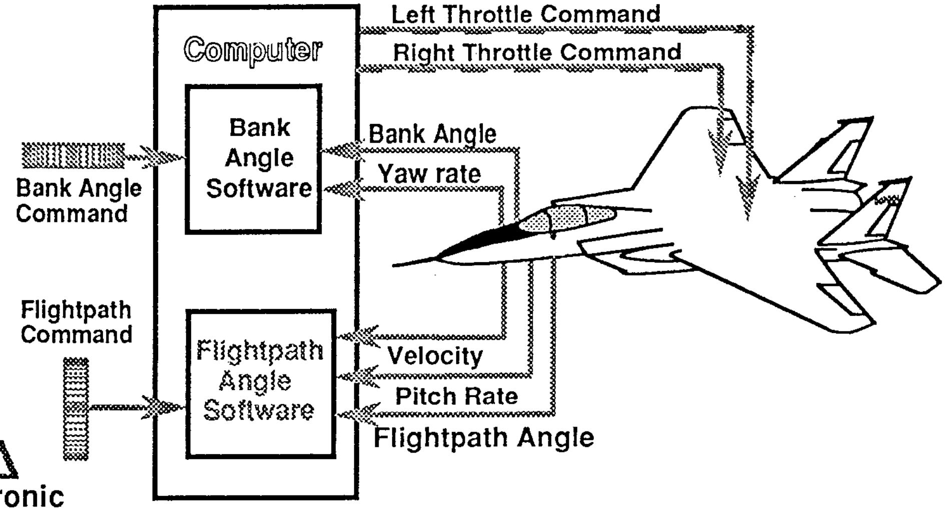
Usually unsatisfactory for safe runway landing

Something else needed for safe runway landings

Propulsion Controlled Aircraft (PCA) - F-15 Results

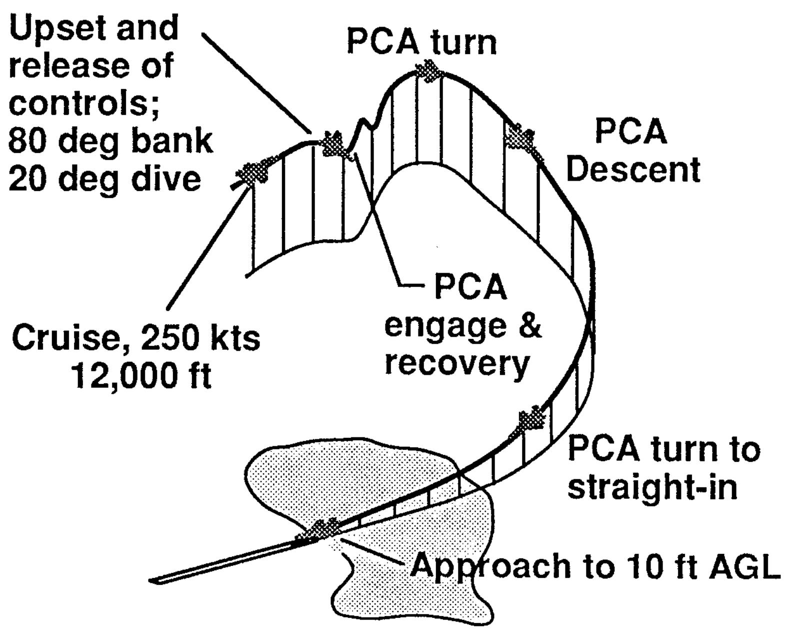
NASA
FWB 94-42



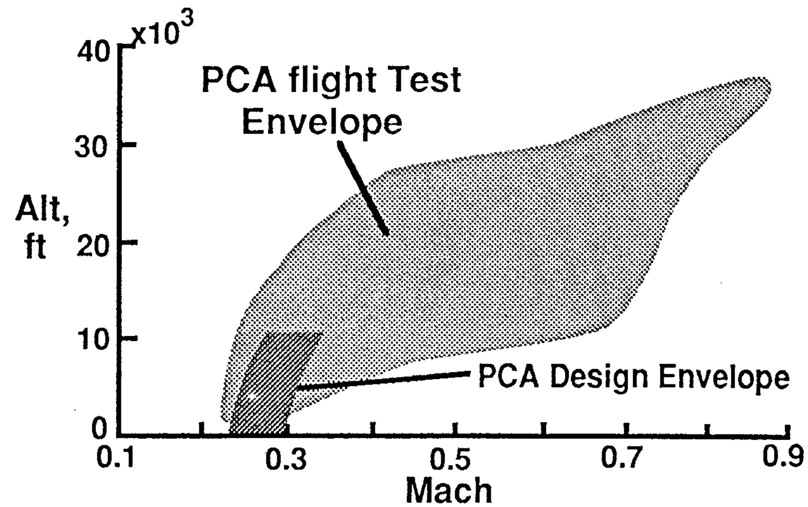


Augmented PCA Block Diagram

Simulated hydraulic failure, PCA recovery, approach to landing
(Flown by all guest pilots)



PCA Design and actual test envelope

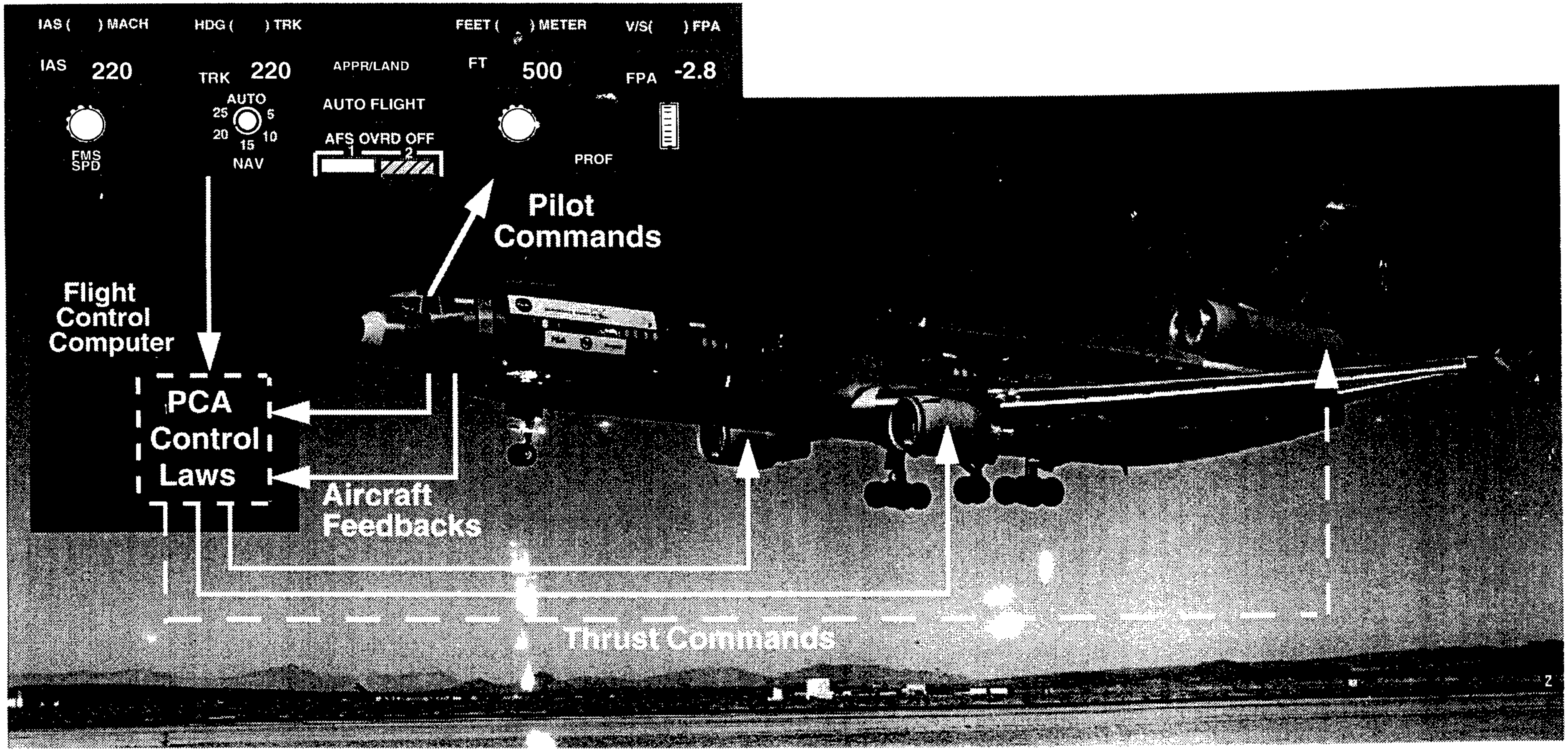


Results: PCA concept proven for backup control for current and future designs

MD-11 Propulsion Controlled Aircraft System

NASA
FWB 97-25

Software changes to existing systems



- Safe landings without using any flight controls
- Goals exceeded ahead of schedule and under cost
- Demonstrated to 21 airline, DoD, FAA, Boeing and Airbus pilots

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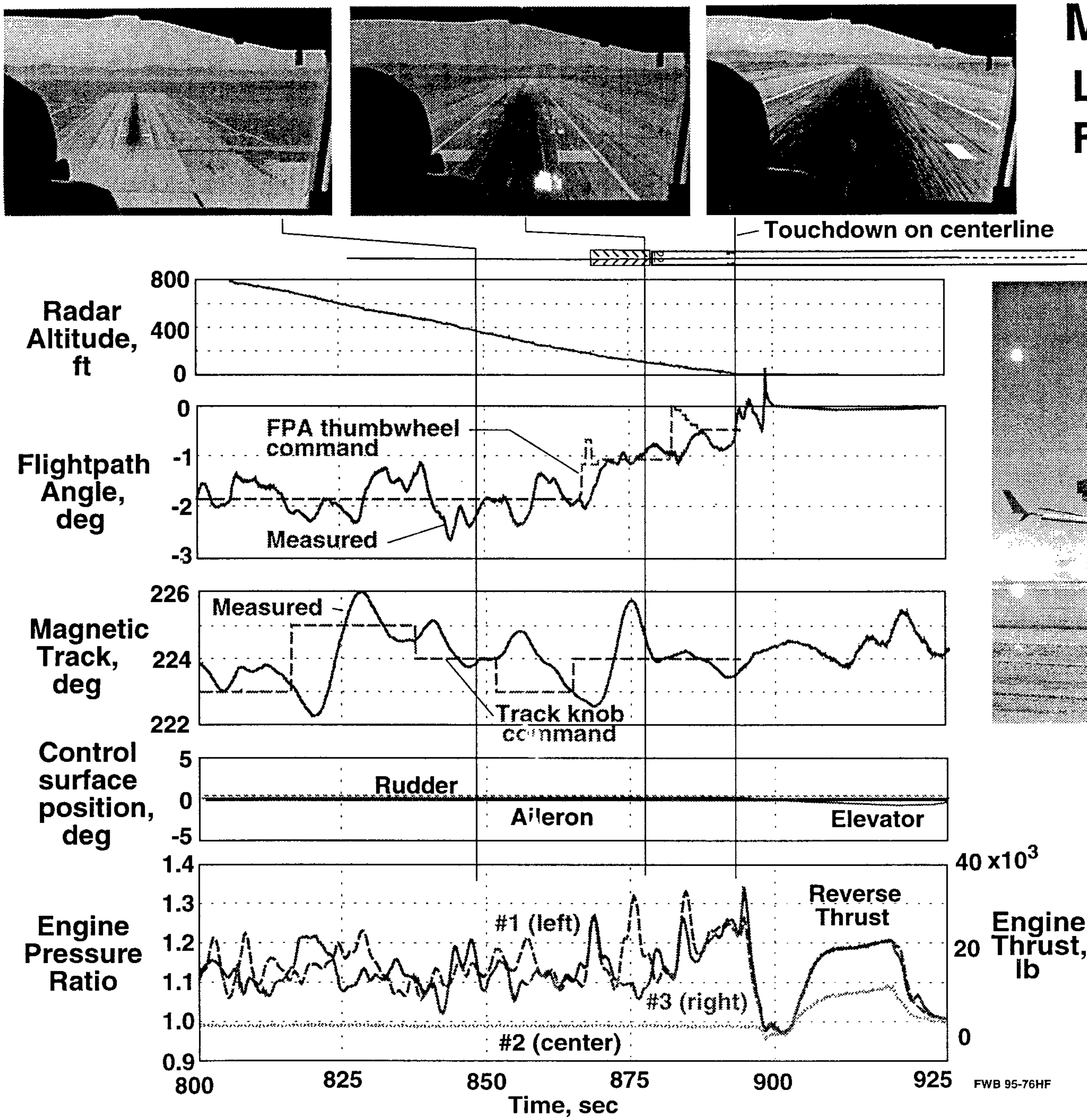
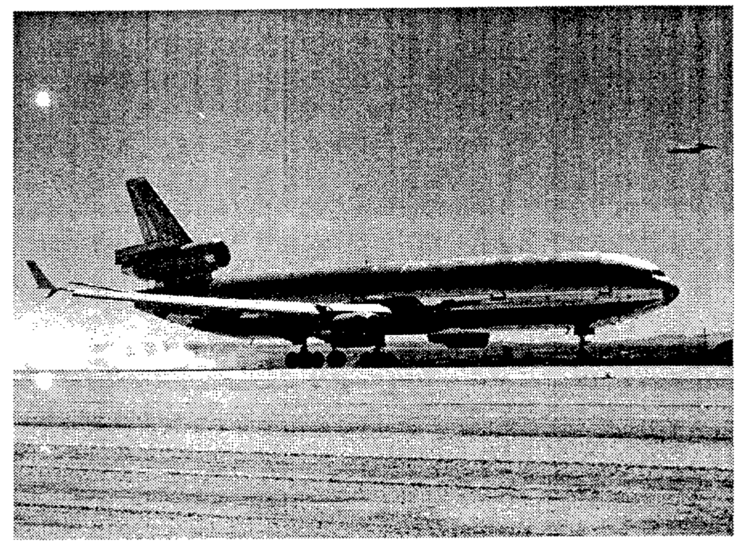
MD-11 PCA Landing

Light turbulence
Flaps 28, 175 kts





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Propulsion Controlled Aircraft (PCA) B-747 at Ames

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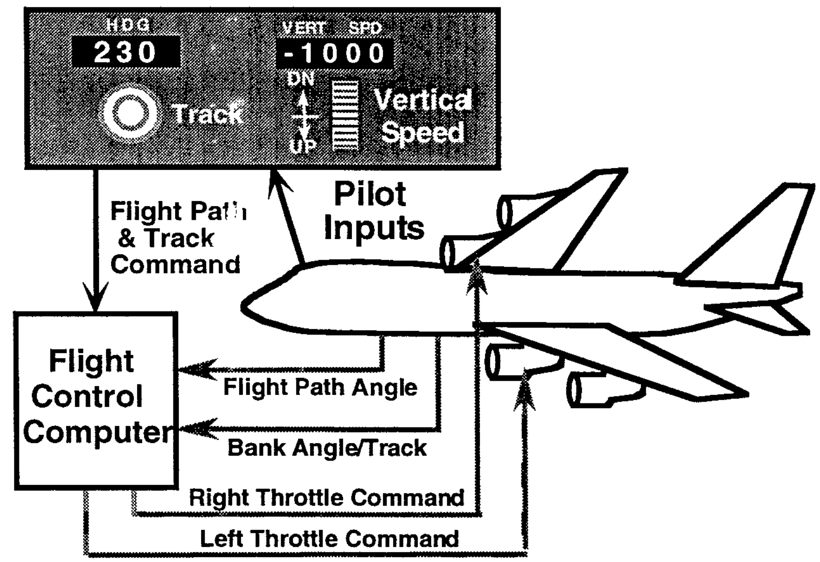
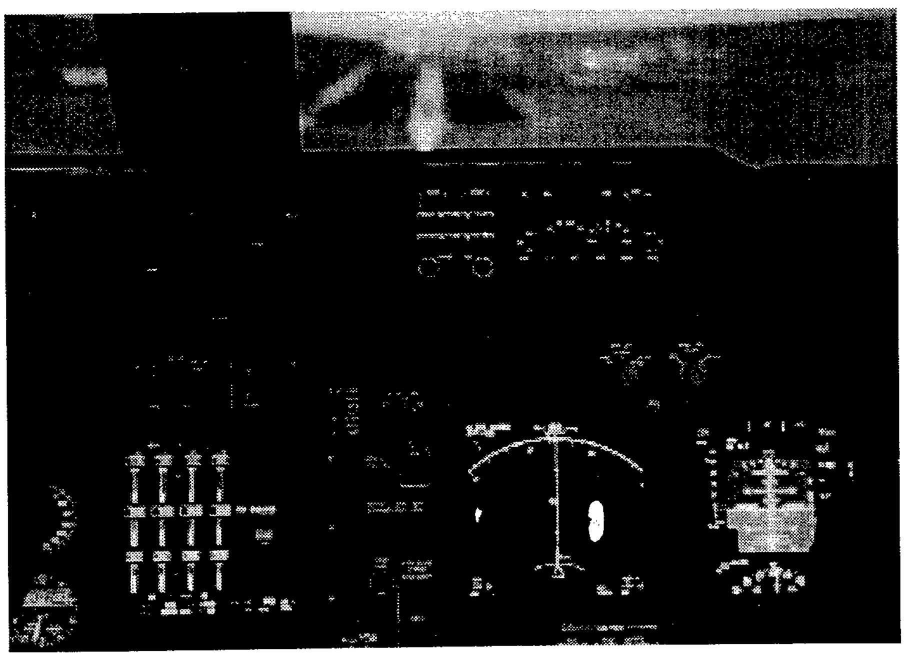
FWB 97-14a

- NASA Ames/FAA Boeing 747 simulator; Level D high fidelity, motion base
- PCA implemented, pilots use existing vertical speed and track knobs
- Also PCA ILS-coupled landing mode
- PCA evaluation by NASA, Boeing USAF & Industry pilots



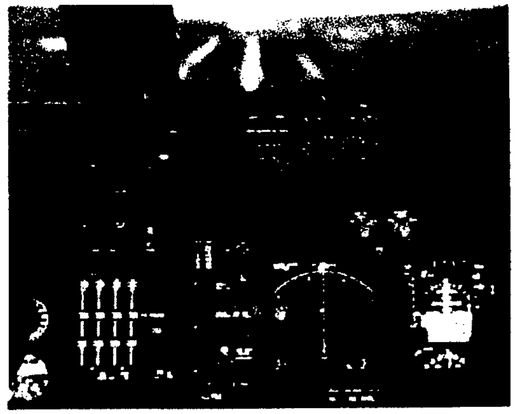


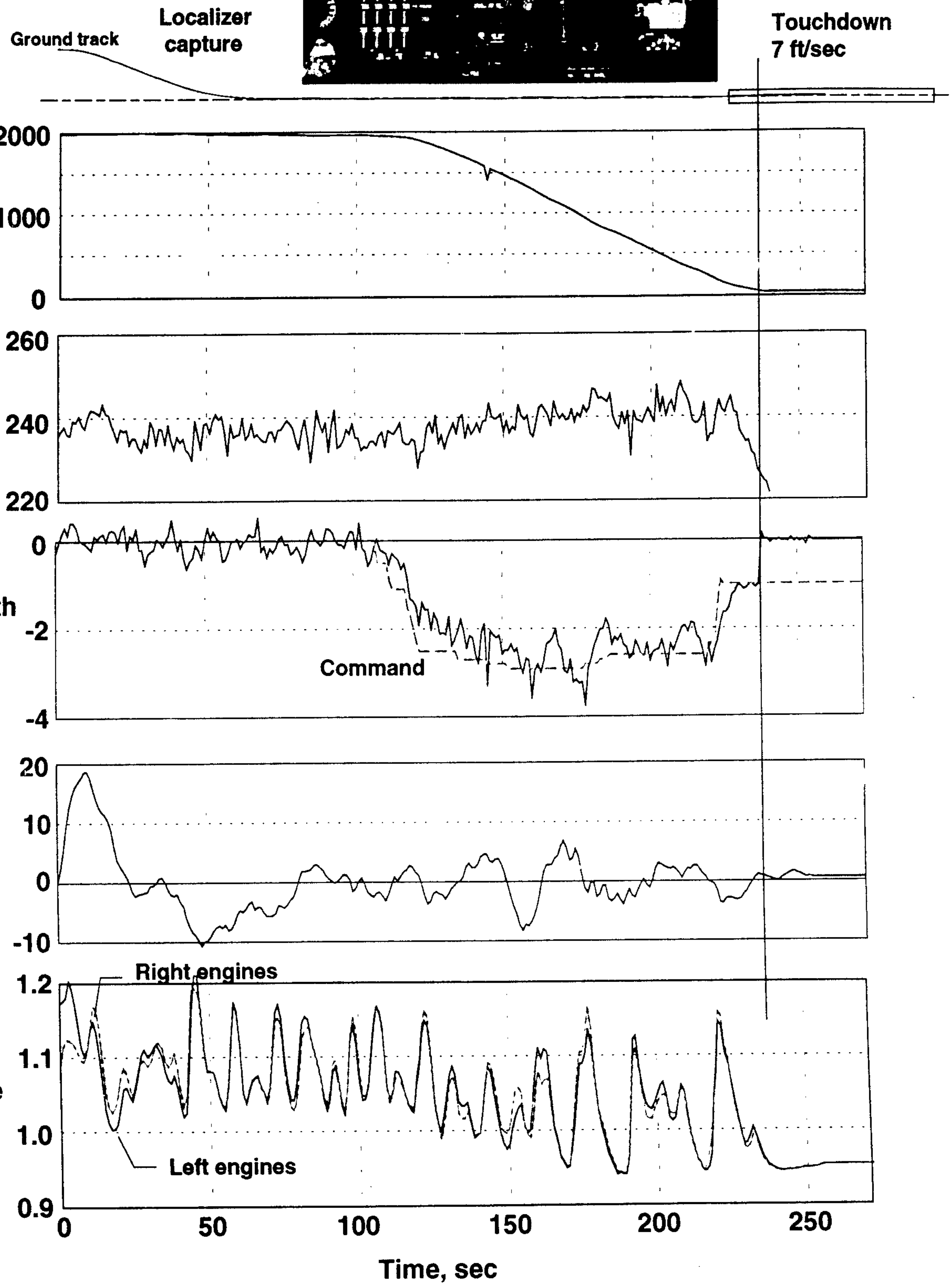
- Tests in 1996 - works very well, similar to MD-11 PCA
- ILS-coupled approach
  - handles higher turbulence levels
  - no crew training required
- Flown by Boeing 747-X chief pilot and Sioux City Flt 232 pilot Dennis Fitch
- Boeing request for aft CG cases tested
- Faster-cheaper PCA concepts tested

B-747 PCA Landing

No hydraulics, no flaps, Localizer-coupled, crosswind and turbulence
Capt. Dennis Fitch, UA 232 pilot, Ames B-747-400 simulator

NASA
FWB 97-07



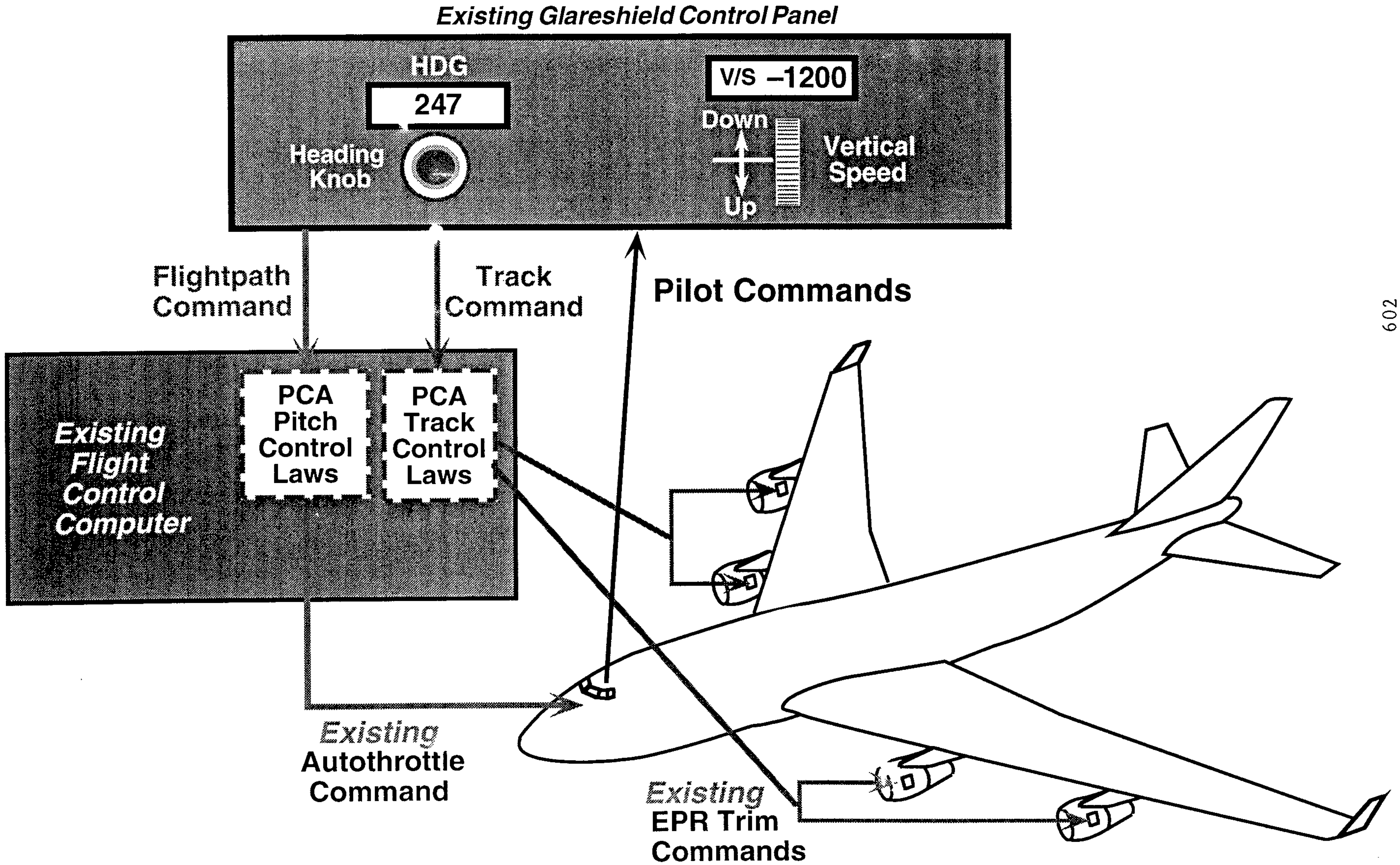


B-747 "PCA Lite"

Faster - Cheaper and Maybe Good Enough PCA

NASA
FWB97-15GL

Uses existing autothrottle loop for pitch control
Uses existing engine trim loop for lateral control



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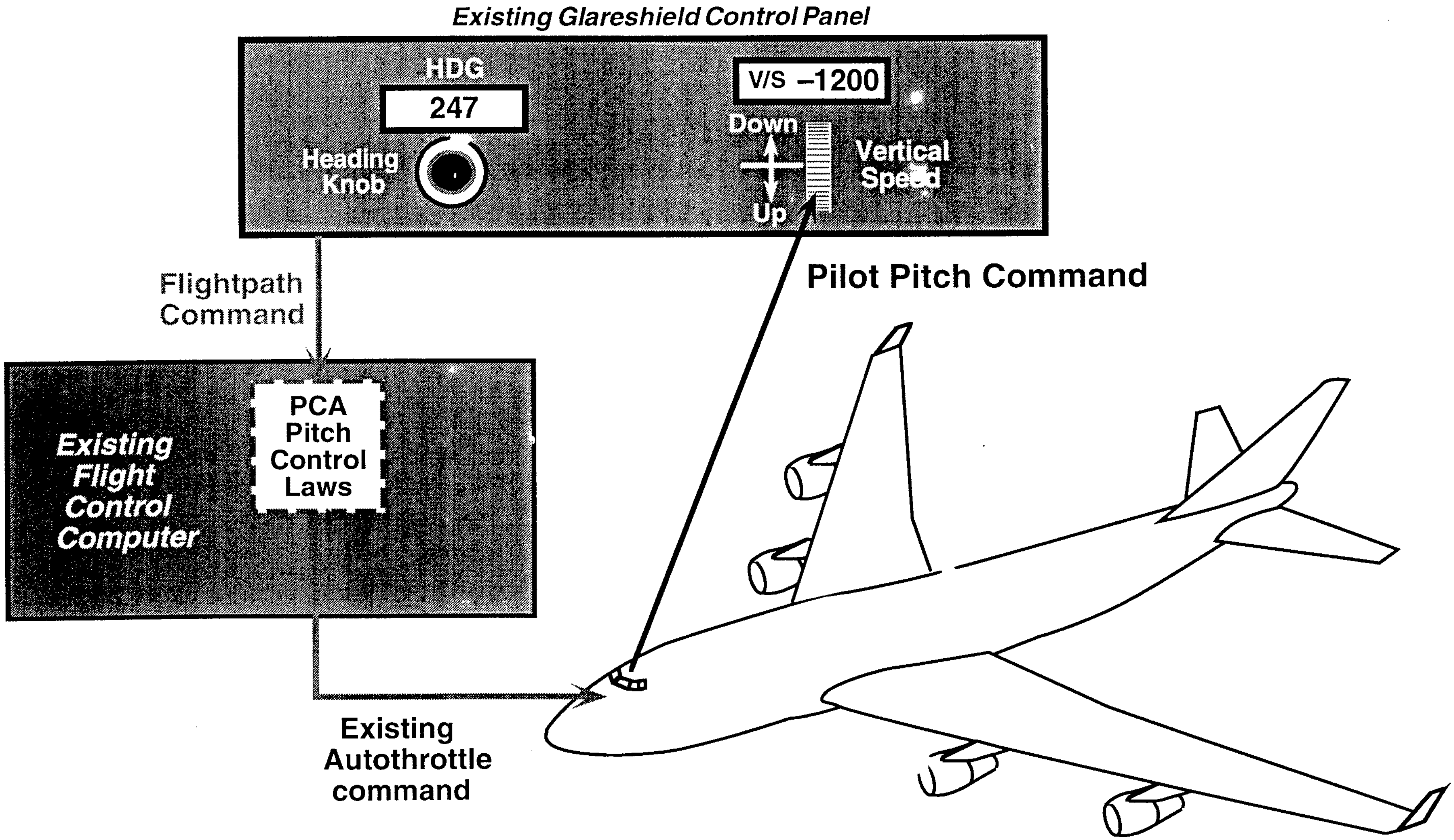
B-747 "PCA Ultra-Lite"

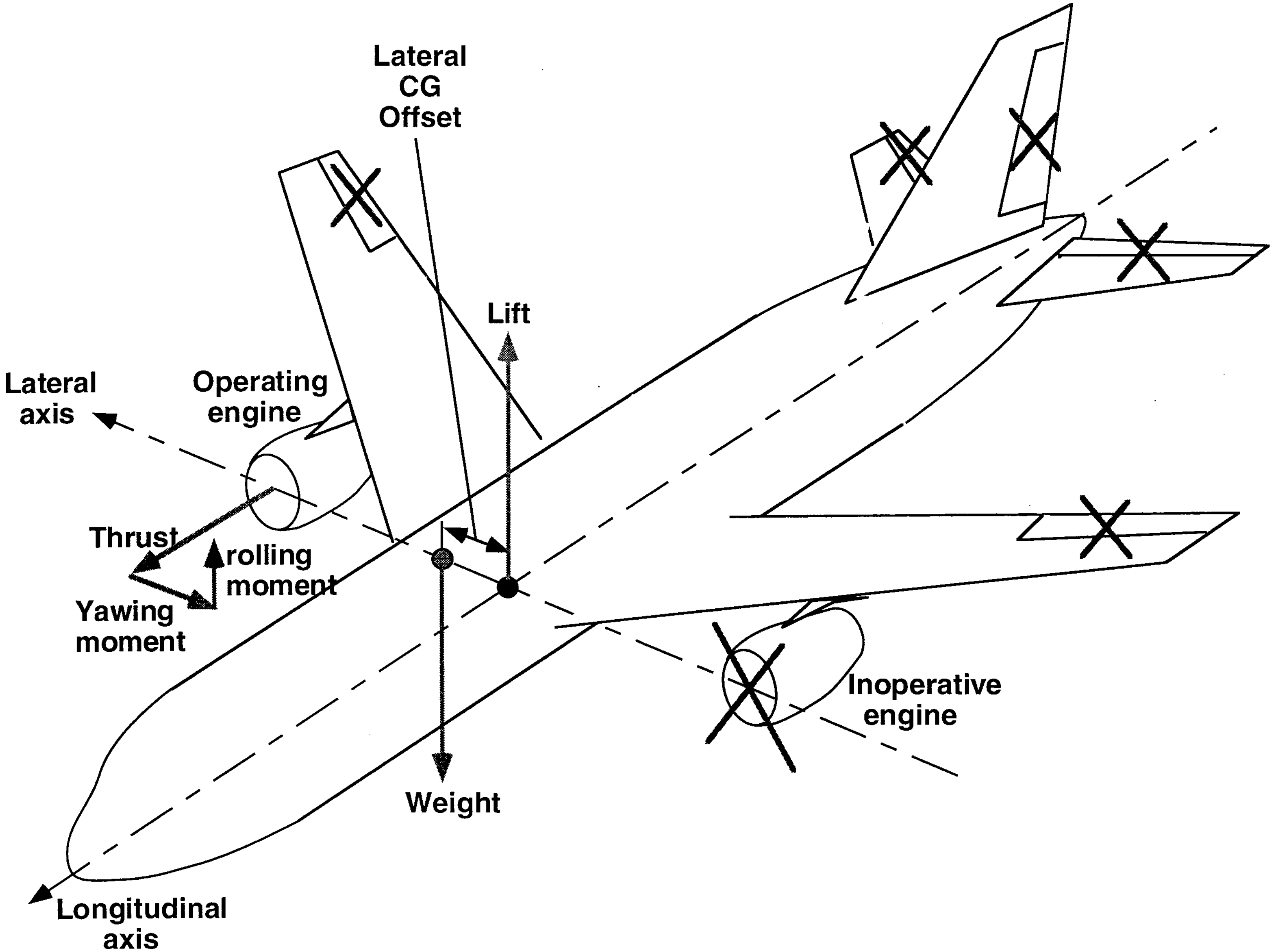
Faster - Cheaper and Maybe Good Enough PCA

NASA
FWB97-15UL

- Uses existing autothrottle loop for pitch control
- Uses pilot manual throttle input for lateral control



Controls Out, Wing Engine Out and Lateral CG Offset



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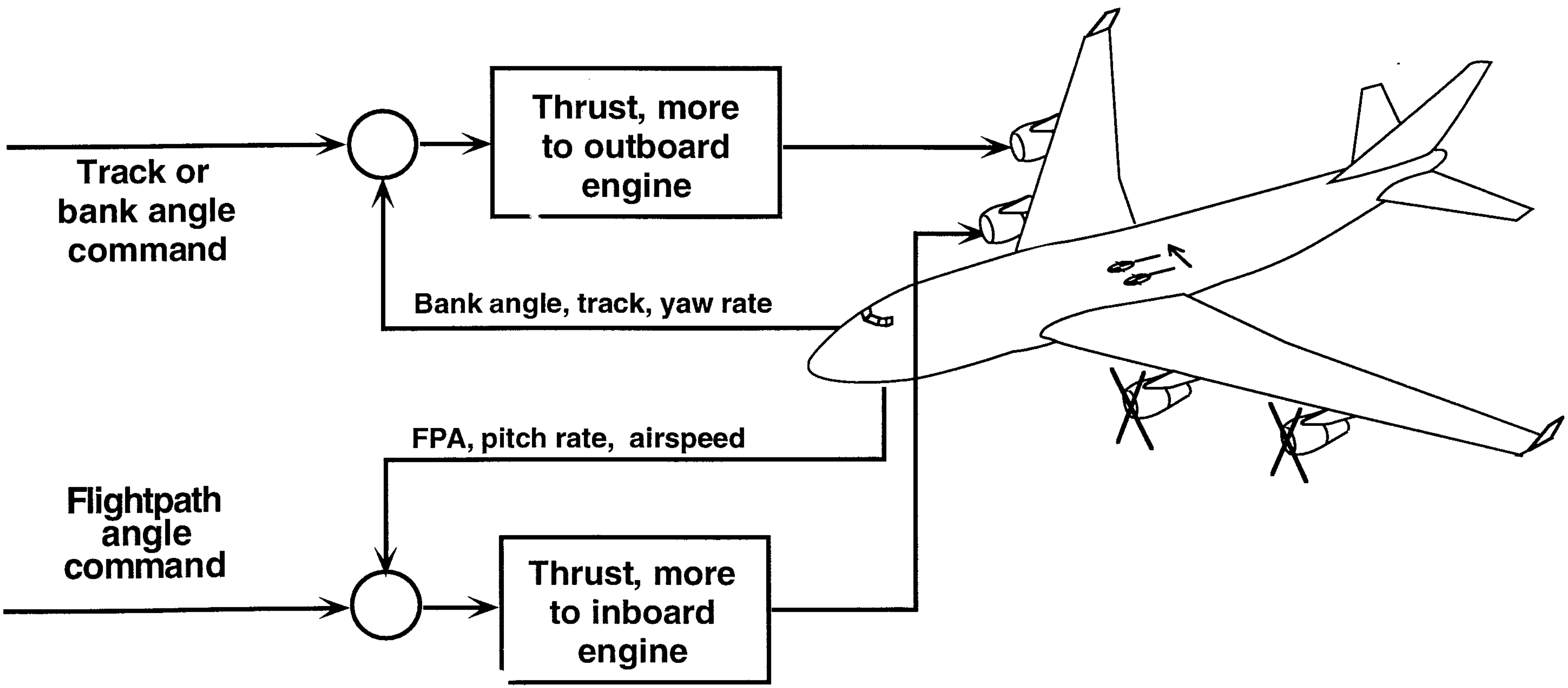
B-747 Control with Lateral CG Offset
No flight controls, both left engines out
CG shifted to side with good engines



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How damage-tolerant is PCA?

NASA
FWB 97-55

Lateral:

Rudder offsets input into simulations to simulate lateral asymmetry

- Control maintained until an engine(s) gets to or near idle power

For approaches on a 2.5° glideslope:

- 5° of rudder on B-747
- 5° of rudder on MD-11 with flaps down
- 4° of rudder on MD-11 with flaps up

Longitudinal:

Trim speed a function of stab setting, CG, and damage

Use CG shift, gear extension, fuel dump, and thrust to change trim speed

Summary

NASA
FWB 97-54

Throttles-Only Control - Manual

- OK for up-and-away flight
- Not adequate for landing

Full PCA System

- Flight tests: Safe landings made in F-15, MD-11
- Simulations: Safe landings in B-747, C-17, B-757

Simplified PCA

- PCA Lite - Works well for B-747
- PCA Ultra-lite - Looks promising

Wing-engine(s)-out – may work with lateral CG transfer

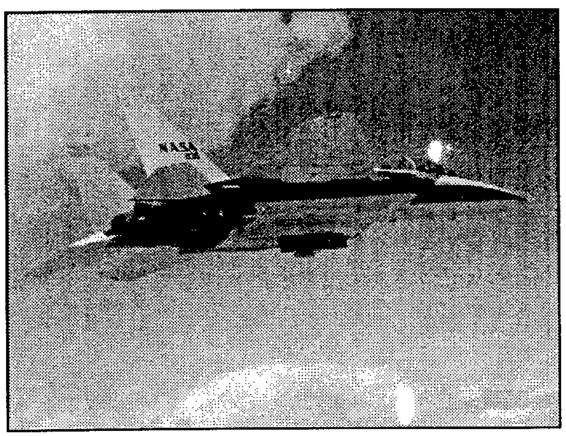
Overall, a promising technique for improving survivability and safety

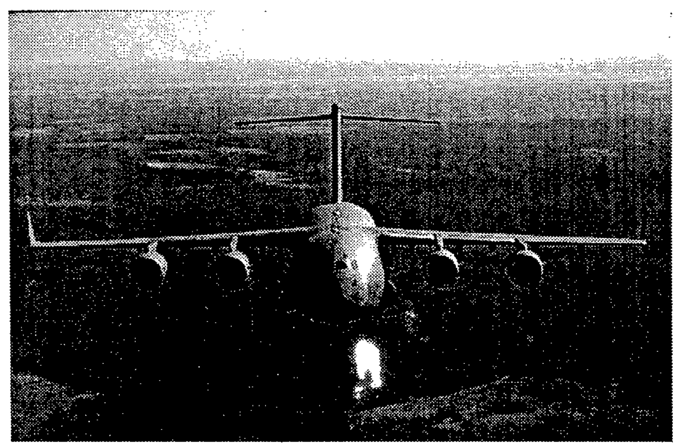
PCA Follow-On Program

NASA, working with other agencies as part of the national safety program, is developing a follow-on system to PCA called Intelligent Damage-Adaptive Control System (IDACS)

IDACS will, using advanced techniques,identify a problem and advise the crew as to needed actions. It may also in a later form, reconfigure the control system to use all remaining control effectors (control surfaces, engines, flaps, CG, etc) to maintain control

NASA, the FAA, USAF, ındustry and universities are currently planning the IDACS project. Simulation studies are already underway using the C-17 and F/A-18 airplanes as models.





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